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RESEARCH PAPER

Manipulating integrated pest management technique by using marigold intercropping and foliar vegetable extracts in tomato (*Lycopersicum esculentum* Mill.) crop

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Abstract

Tomato is one of the global crops essential for nutritional security. In Pakistan tomato cultivation is threaten by pest infestation including aphids, whitefly, lepidopteran, leaf minors, mealy bug, red spider mites and nematodes. These pests are severely destroying the crop. This research study was conducted to find out the efficiency of two bio-friendly techniques to reduce pest pressure in tomato c.v anna in an eco-friendly way, and to check the efficiency of vegetable extract in increasing crop yield. Tomato plants were planted in four blocks. In first block, tomato were planted alone as a control (T0), in 2nd block, marigold was planted with tomato as a companion crop (T1), in 3rd block, tomato plants were sprayed with vegetable extract (6 g l^{-1}) (T2) and in 4th block, tomato plants were planted with marigold in combination with foliar application of vegetable extract (6 g l^{-1}) (T3). Tomato fruits were harvested at maturity, and they were analyzed. Plant samples in control block showed least performance for all parameters especially in fruit yield and pest incidence. Similarly, mealy bug count and white fly was high in control block as compared to other blocks. Marigold intercropped block received foliar application of vegetable extract have good number of fruits, flowers with less damaged fruits and leaves were recorded. © 2025 The Author(s)

Keywords: Companion crop, Marigold, Pest pressure, Tomato, Vegetable extract

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Introduction

Tomato (*Lycopersicum esculentum*) belongs to family *Solanaceae* and it is native to the Andean region in South America (Lin et al., 2014). It is one of the most widely cultivated and economically important vegetable crops across the globe due to its high nutritional value and versatile use in daily diets. As global demand increases, especially in developing countries like Pakistan, ensuring sustainable production and pest management practices has become a critical agricultural priority. The leading tomato producing countries are China, USA, Turkey, Egypt, Iran, Italy, Brazil and Spain. The major growing areas of tomato in Punjab, Pakistan are Okara, Sahiwal and Faisalabad. Main varieties grown are introduced from other countries mainly from America and Europe some of commonly grown tomato varieties are Rio Grande, Anna, Roma and Moneymaker (Khokhar, 2013; Shah et al., 2019). Among agricultural products onion, tomato and chilies are the most consumable vegetables in Pakistan and other South Asian countries (Lohano & Mari, 2005). Tomato constitutes about 72 % value among fresh vegetables grown all around the world which makes it the most important vegetable crop (Hanssen et al., 2010). As it has 192 million metric tonnes of production worldwide and in 2023 its value was over 150 billion approx. in international dollars (Food and Agriculture Organization of the United Nations [FAO], 2016). Export of tomato production of world especially from Pakistan has been increasing since 2007. Pakistan`s share in world export of tomatoes is negligible. Pakistan is among fast growing nations in tomato production by 8 % in area and 5 % in production (Tahir et al., 2012).

With the increase in population, the domestic needs and demand for tomato have also been increased. It is used on daily basis in many dishes and as ketchup, salad, and other food items. Tomato is available in markets around the year as it is cultivated in different places round the year (Chohan & Ahmad, 2008). Tomato is one of the leading vegetable crops just fell short to potato because it is high in nutrient contents and is being grown over worldwide. It contains vitamin A, B and C and is used for different food uses. Tomatoes contribute almost 20 % requirement of vitamin A per day in the form of calorie diet. As taking vitamin C, tomato shares 26 % in our daily requirements. Tomato is also useful against different diseases as it can cure cancer due to an antioxidant lycopene (Adenuga et al., 2013). Tomato fruit contains water ranging from 92.5 – 95 % and dry matter 5 - 7.5 %.

A wide range of insect pests and pathogens affect tomato productivity (Csizinszky et al., 2005). These pests hinder its growth and reduce its yield, damage tomato plant organs (leaf, stems, leaflets, buds, roots, twigs, fruits and flowers). Tomato is also affected by many bacterial diseases which hinder its productivity either in open fields or in greenhouses. Significant destruction on crops and key financial harms is done by a vast variety of aphids (Ahmad & Ahmad, 2018; Ali & Shahid, 2018; Ashraf, 2018). Whitefly is responsible for up to 100 % yield damage which makes it most devastating tomato pest. Synthetic insecticides are being used extensively by many farmers for effectively controlling white fly which has also caused trouble for the humans and environment (Abbas &

Shafique, 2019; Jamilah et al., 2024). Their application resulted in the killing of eco-friendly insects, ecological damage, pollutes soil and water sources, destroys entomological communities, and became reason of pathologic changes in many animal and plant populations (Abbas, 2022; Awe & Adelakun, 2024). Chemical control develops resistance, so it is not recommended despite its vast action against pests because it is responsible for environmental disturbance (Balestra et al., 2009). Companion cropping is a type of planting when two plants are grown in proximity to get their beneficial, synergistic enhancement effects on the growth and yield of each other. Marigold also has synergetic effects on different vegetables (Shah & Ahmad, 2020). Vegetable extract can reduce insect incidence and help get good yield (Qasim et al., 2023). Agronet covers with companion cropping could elevate this effect and could efficiently be used as a management technique for pest management in tomato against whiteflies (Mutisya et al., 2016). Therefore, this research study was aimed to evaluate the effect of pre-harvest foliar spray of vegetable extract and synergetic effects of marigold on growth quality and yield of tomato and also to screen out the pest control ability of marigold and vegetable extract spray.

Material and Methods

The present research was conducted at the research field near University Market, Department of Horticulture, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi (33° 40' N, 73° 10' E).

Experimental plant material

Research was carried out from March to July 2018. Nursery of tomato and marigold was raised in nursery trays and transplanted in first week of May 2018. The treatments were consisted of different vegetable extract (cucumber, tomato, chillies, bitter gourd and bottle gourd along with sugar). Field trial consisted of four blocks. Tomato plant was kept as control while other three treatments were tomato plants with marigold, tomato plants having vegetable extract, tomato plants having vegetable extract and marigold intercropping (Table 1).

Table 1 Treatments used in the experiments

Treatments	Description
T0	Control
T1	Marigold companion + Tomato
T2	Foliar application of vegetable extracts (0.6%)
T3	Marigold companion + Tomato + Foliar application of vegetable extract (0.6%)

Insect parameters studied

Type of insect per plant was observed through visual identification. Number of pests on each plant was counted by normal observation.

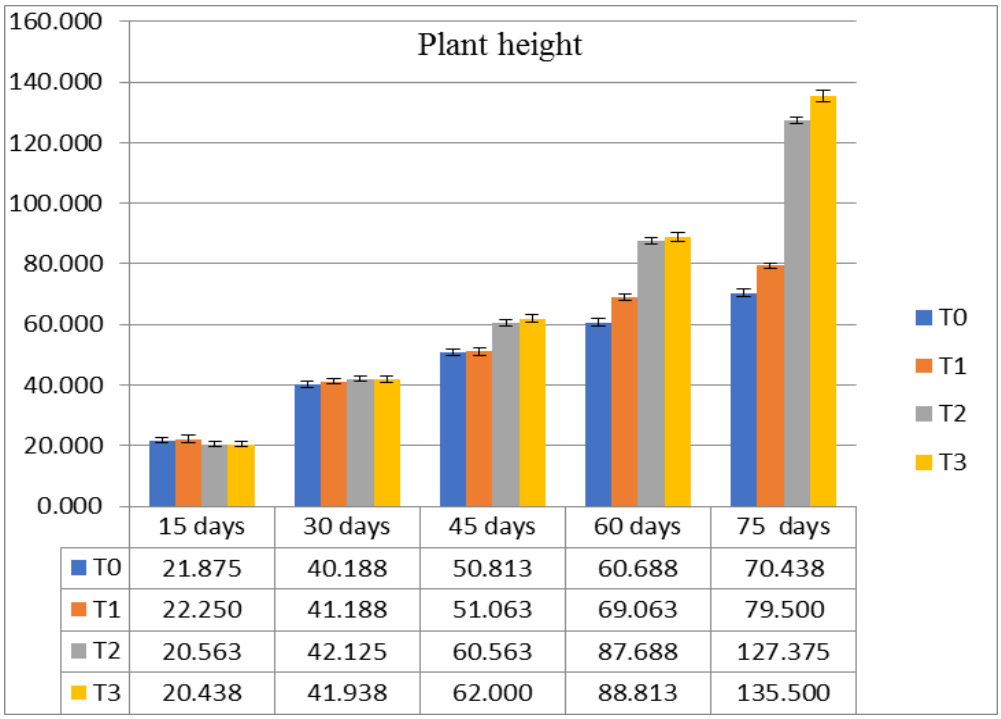
Statistical analysis

This experiment was done in two factorial Randomized Complete Block Design. The analysis of variance was followed by Steel et al. (1980). Least significance difference test (LSD test) was used to measure significance. Window based software Statistic 8.1 was used to form the analysis.

Results

Effect of intercropping and plant extract on tomato Plant height (cm)

Plant height across different time intervals showed significant differences in mean values. At 75 days after transplanting, the maximum average plant height 103.2 cm (Fig. 1) was observed, while the lowest (21.28 cm). was recorded at 15 days after transplanting A consistent increase in plant height was observed with mean values of 41.36, 56.11 and 76.56 cm, at 30, 45 and 60 days after transplanting, respectively. Among treatments, the highest overall mean plant height (69.73 cm) was recorded in T3. The lowest mean height (48.8 cm) was observed in the control group (T0), where no treatment was applied. Treatment T1 (tomato with marigold only) had a mean plant height of 52.61 cm, while T2 (tomato sprayed with vegetable extract only) showed a higher mean of 67.66 cm. These results indicate that both marigold intercropping and vegetable extract application contributed to increased plant height, with the combination of both (T3) being the most effective. Specifically, T3 recorded the maximum plant height of 135.5 cm at 75 days, while the minimum (20.44 cm) was observed at 15 days within the same treatment. In T2, the plant height at 60 days reached 127.38 cm, outperforming other treatments at the same interval. Overall, the application of vegetable extract, either alone or in combination with marigold, had a significant positive impact on plant height. Therefore, the use of vegetable extract is recommended to promote better growth in tomato plants.



	15 days	30 days	45 days	60 days	75 days
T0	21.875	40.188	50.813	60.688	70.438
T1	22.250	41.188	51.063	69.063	79.500
T2	20.563	42.125	60.563	87.688	127.375
T3	20.438	41.938	62.000	88.813	135.500

Fig. 1 Comparative plant height of tomato under integrated pest management treatments from 15 to 75 days after transplanting

Stem diameter (cm)

The stem diameter of tomato plants showed significant variation across different time intervals. The highest mean stem diameter was recorded at 75 days after transplanting (7.77 cm), while the lowest was observed at 15 days after transplanting (3.22 cm) (Fig. 2). A consistent increase in stem diameter was observed over time, with mean values of 4.06 cm at 30 days, 5.20 cm at 45 days, and 6.48 cm at 60 days after transplanting. Among treatments, the highest overall mean stem diameter (5.72 cm) was recorded in T1, where tomato plants were intercropped with marigold. This suggests that marigold intercropping positively influences stem thickness. The control treatment (T0), where no intercropping or foliar spray was applied, showed the lowest mean stem diameter (4.81 cm), significantly lower than the treated groups. Treatments T2 (vegetable extract foliar spray) and T3 (marigold intercropping + vegetable extract) showed mean stem diameters of 5.50 cm and 5.35 cm, respectively. While there was no significant difference between these treatments and T1, all performed better than that of control. These findings indicate that both marigold intercropping and vegetable extract application contributed to improved stem development. The most notable value was recorded in T2 at 75 days after transplanting, with a stem diameter of 8.66 cm, while the minimum was observed in T0 at 15 days (2.81 cm). Some non-significant differences were observed at earlier intervals, particularly in T3 at 15 and 30 days, with stem diameters of 3.87 cm and 3.76 cm, respectively. Overall, the data show that treatments involving marigold and/or vegetable extract had a positive impact on stem diameter compared to the untreated control, with the effects becoming more pronounced over time.

Number of leaves per plant

As shown in Fig. 3, the mean number of leaves per plant varied significantly across all time intervals. The highest mean value was recorded at 75 days after transplanting (105.28), while the lowest was at 15 days after transplanting (12.48). At 60 days, the mean number of leaves was also relatively high (77.69), while the means at 30 and 45 days were 29.77 and 52.14, respectively showing statistically significant differences. In terms of treatments, the data presented in Fig. 3 indicates significant differences among all treatments. The highest mean number of leaves per plant was recorded in Treatment T3 (70.90), where tomato plants were intercropped with marigold and sprayed with vegetable extract. The lowest means was observed in the control (T0), where tomato plants received no treatment (37.34). Treatment T2, where tomatoes were intercropped with marigold but without spray, also showed a comparatively high mean (61.07), close to T3. Treatment T1 (52.56), which involved only the application of vegetable extract, also performed better than the control. These findings clearly indicate that the use of vegetable extract, either alone or in combination with intercropping, positively influenced the number of leaves per plant.

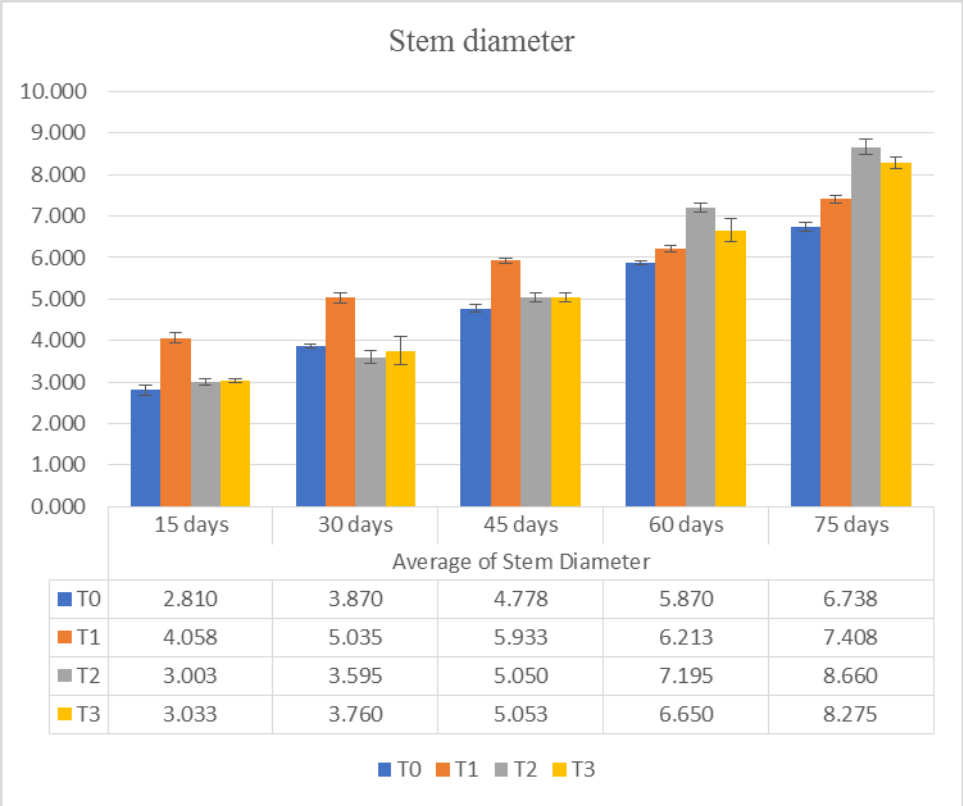


Fig. 2 Mean stem diameter of treatments at different time of tomato

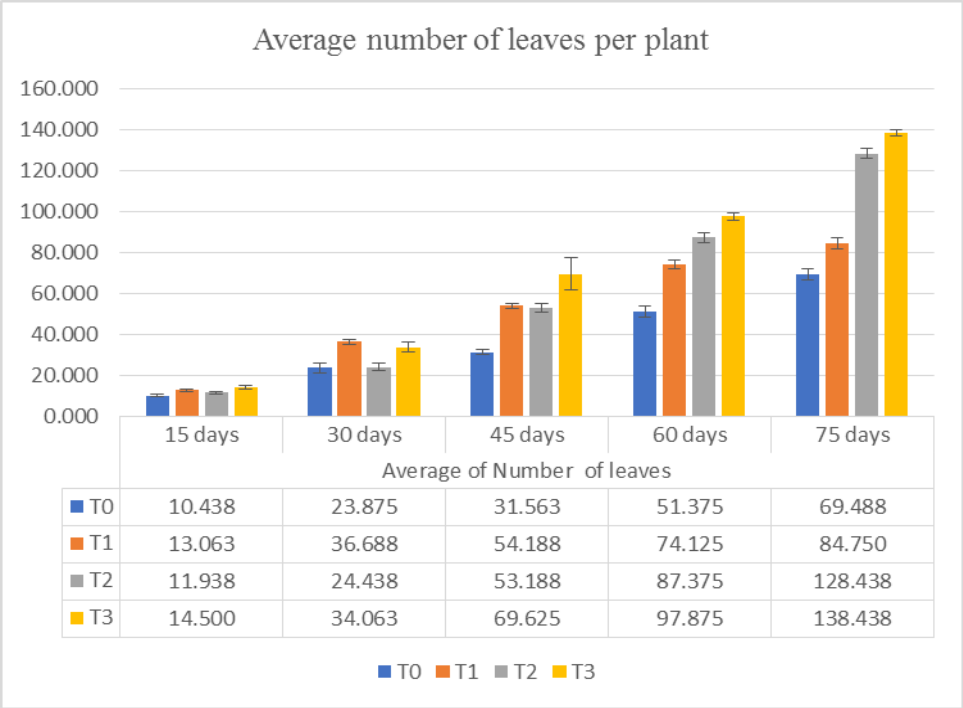


Fig. 3 Mean number of leaves per plant of treatments at different times of tomato

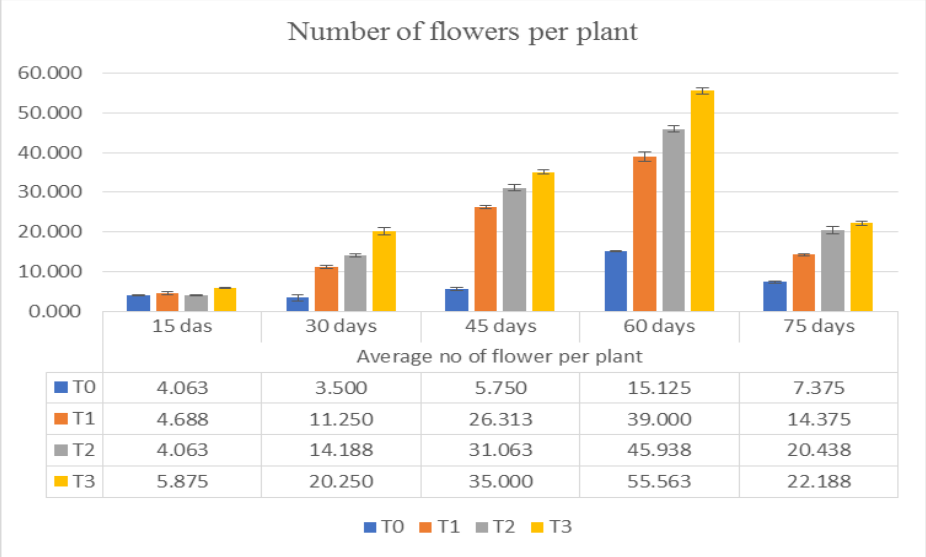


Fig. 4 Mean number of flowers per plant of treatments at different times of tomato

Number of damaged flowers per plant

As shown in Table 2, the number of damaged flowers per plant across time intervals did not differ significantly. The highest mean value was recorded at 75 days after transplanting (4.23), followed by 60 days (3.60). The lowest was at 15 days (0), while intermediate values at 30 and 45 days were 0.84 and 2.53, respectively. Similarly, treatment data showed no statistically significant differences. However, the highest mean number of damaged flowers was observed in T2 (4.21), where tomato plants were sprayed with vegetable extract, followed closely by the untreated control T0 (4.06). The lowest damage was recorded in T3 (0.30), where plants were both intercropped with marigold and sprayed with vegetable extract. This indicates that combining marigold with botanical extracts offer enhanced protection against flower-damaging pests. Regarding the interaction between time and treatment, the highest mean value (7.75) was found in T0 at 75 days, suggesting that the absence of pest control led to severe flower damage. The second-highest damage occurred in T3 at 60 days (7.43), possibly due to a temporary pest surge. The lowest value (0) was observed in T3 at 30 days, confirming the effectiveness of marigold and extract in early stages.

Number of fruits per plant

The number of fruits per plant significantly differed across all time intervals (Table 2). The highest mean value was observed at the 75-day interval (26.10), followed by the 60-day interval (21.15). The lowest mean was recorded at the 15-day interval (0.063). The 30-day and 45-day intervals also showed significant differences, with mean values of 3.93 and 12.20, respectively. Similarly, Table 2 shows that the number of fruits per plant also varied significantly among treatments. The highest mean value (16.78) was recorded in treatment T3, where tomatoes were intercropped with marigold and received foliar application of vegetable extract. This indicates that T3 was the most effective treatment for increasing fruit yield. It was followed by T2 (14.22), where only vegetable extract was applied. The control treatment (T0), which involved no intercropping or foliar spray, had the lowest mean value (7.63). T1, where tomatoes were intercropped with marigold only, had a mean fruit count of 12.12, also showing a significant improvement over the control. Furthermore, combined analysis of treatment and time showed that the interaction between these factors was also significant. The highest mean fruit count (34.93) was recorded in T3 at the 75-day interval, indicating that intercropping with marigold and applying vegetable extract over a longer period produced the best results. This was followed by T2 at the 60-day interval (30.12). The lowest mean value (0.00) was observed in T3 at the 15-day interval, suggesting that shorter durations are not sufficient for treatment effectiveness.

Table 2 Effect of marigold as a companion crop and foliar application of vegetable extract on number of damaged leaves per plant, days to flower bud emergence, number of damaged flowers per plant and number of fruits per plant in tomato

Treatments	Days	NDLPP	DFBE	NDFPP	NFPP
T_0	15	0.000^{e}	0.6250^{b}	0.000^{h}	0.000^{e}
	30	2.750^{c}	0.000^{c}	1.312^{de}	2.750^{i}
	45	1.581^{b}	0.000^{c}	4.500^{c}	4.750^{i}
	60	1.562^{b}	0.000^{c}	6.750^{b}	14.25^{gh}
	75	10.563^{a}	0.000^{c}	7.750^{a}	16.43^{f}
T_1	15	0.000^{e}	0.7500^{ab}	0.000^{h}	0.250^{k}
	30	0.000^{e}	0.000^{c}	0.125^{h}	4.875^{i}
	45	1.062^{cde}	0.000^{c}	0.250^{gh}	13.938^{h}
	60	1.512^{cde}	0.000^{c}	0.625^{fgh}	18.625^{e}
	75	1.312^{cde}	0.000^{c}	1.000^{f}	16.438^{f}
T_2	15	0.000^{e}	0.7500^{ab}	0.000^{h}	0.000^{e}
	30	1.312^{cde}	0.000^{c}	1.937^{d}	2.937^{j}
	45	1.312^{cde}	0.000^{c}	5.125^{c}	14.500^{gh}
	60	1.625^{cd}	0.000^{c}	6.562^{b}	23.563^{d}
	75	2.062^{cd}	0.000^{c}	7.437^{a}	30.125^{b}
T_3	15	0.000^{e}	0.8750^{a}	0.000^{h}	0.000^{e}
	30	0.000^{e}	0.000^{c}	0.000^{h}	5.187^{i}
	45	0.625^{cde}	0.000^{c}	0.250^{gh}	15.625^{fg}
	60	1.750^{cde}	0.000^{c}	0.500^{fgh}	28.188^{c}
	75	1.750^{cde}	0.000^{c}	0.750^{fgh}	34.938^{a}

NDLPP = Number of damaged leaves per plant; DFBE = Days to flower bud emergence; NDFPP = Number of damaged flowers per plant; NFPP = Number of fruits per plant; Means followed by a same letter are not significantly different at p = 0.05

Number of damaged fruits per plant

The number of damaged fruits per plant for all time intervals showed non-significant data as highest mean value was recorded at 75 days interval (2.42) followed by mean of 60 days (1.45) (Table 3). The lowest mean value was recorded at 30 days interval (0) and almost same value was recorded at 15 days (0) because there was not much attack of insects in first 5 to 30 days. As stated in Table 3 the data for number of damaged fruits per plant for all the treatments showed a non-significant result as highest value was recorded in control (1.72) in which tomato plants were planted without any treatment followed by T_1 (0.88) in which tomatoes were intercropped with marigold. Least result was recorded in T_3 (0.76) where tomatoes were intercropped with marigold and sprayed with vegetable extract also T_2 (0.76) in which tomato plants were sprayed with vegetable extract. So, this data showed that when we plant tomatoes without any treatment in T0 it becomes the place for insect pest attack to attack freely so ultimately number of damaged fruits were on a higher side as compared to other treatments in which vegetable extract and marigold hinder the insect pests, so a smaller number of damaged fruits were recorded. Least value of mean was recorded in T_3 (0) at 45 days interval in which tomato plants were intercropped with marigold and sprayed with vegetable extract. A gradual increase in fruit damage was observed with crop age, peaking at 75 days after transplanting. The control treatment (T0) consistently exhibited a higher number of damaged fruits compared to all other treatments. Treatments involving marigold intercropping and/or vegetable extract application (T1, T2, and T3) maintained lower mean damage values, reflecting reduced pest pressure. Moreover, no fruit damage was recorded in T3 at the 45-day interval, indicating a possible synergistic effect of combined pest management practices.

Average fruit weight (g)

The average fruit weight for all the time intervals gave significant mean values as highest was recorded at 75 days interval (97.87 g) followed by 60 days interval (63.89 g) (Fig. 5). Lowest mean value was recorded at 15 days interval (0.53 g). As stated in Fig. 5 the data for average fruit weight for all treatments showed insignificant data as highest mean value was recorded for T_3 (54.20 g) when tomato plants were intercropped with marigold and sprayed by vegetable extract was just more than T_2 (53.43 g) when tomato plants were sprayed with marigold. Least mean value was recorded in T_0 (30.56 g) when tomato plants were planted without any treatment. In T_1 (35.50 g) when tomato plants were intercropped with marigold also showed better mean value as compared to T_0 (30.56 g) when tomato plants were planted without any treatment. So, this data showed that vegetable extract had a clear effect on fruit weight ultimately increasing yield. Marigold also has a positive impact on fruit weight because it hinders insect pests so ultimately give the time for tomato plants to flourish and get good quality fruit. As stated in Fig. 5 the data for average fruit weight for both treatment and time showed insignificant results as highest mean value was recorded with T_3 (120.69 g) at 75 days interval

followed by mean of T_2 (115.75 g) when tomato plants were planted with marigold at 75 days interval. The lowest mean value was recorded in T_3 (0) when tomato plants were intercropped with marigold and sprayed by vegetable extract at 15 days interval.

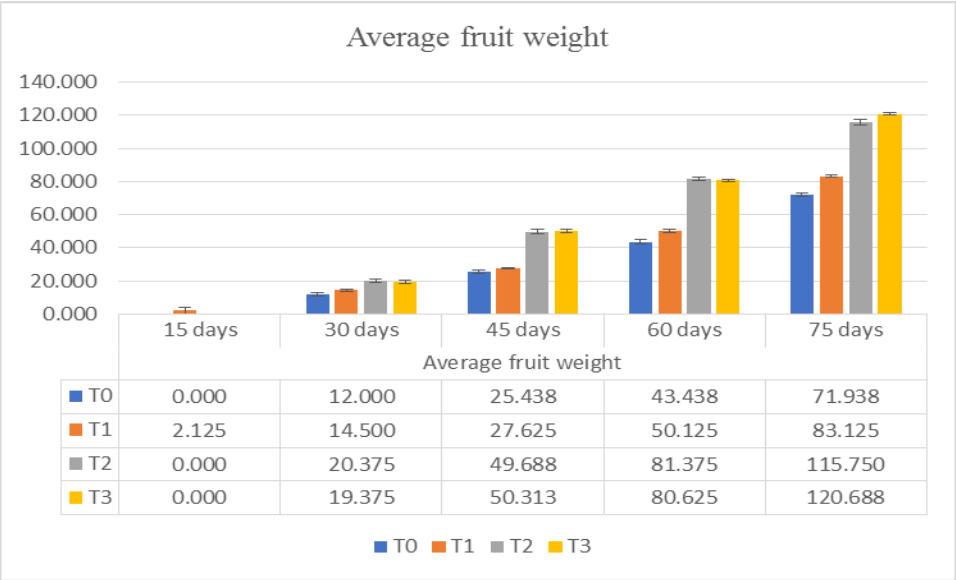


Fig. 5 Mean Average fruit weight of treatments at different time of tomato

Type of insects per plant

Data for type of insect per plant for all time intervals showed significant difference from one another (Table 3) with the highest mean value at 45 days interval (0.50) least on 15 days interval (0.06). Other time intervals did not show much significance level as on time intervals of 75, 60 and 30 days it was (0.50), (0.25) and (0.25) respectively. As stated in Table 3 the data for types of insects for treatments showed no significant difference from one another. As, highest mean value was recorded in control T_0 when tomato plants planted without any treatment with mean of (0.60) shows that it has highest number insect attacking followed by T_1 when tomato plants intercropped with marigold with mean value of (0.20). Other two treatments were also not much significant as the mean value showed for T_3 in which tomato plants were intercropped with marigold and sprayed with vegetable extract and T_2 when tomato plants sprayed. With vegetable extract which is (0.20) and (0.10) respectively. Results showed that mealy bug and white fly attacked the field crop, but infestation was not so high compared to Control T_0 when tomato plants planted without any treatment. Number of damaged flowers and fruits was so less than control T_0. As stated in Table 3 data of type of insects for both time and all treatments showed no significant difference from one another. As, highest mean value was recorded in T_0 at 45 days (1) time interval which showed that it has the greatest number of different types of insect pests attacking followed by T_0 at 60 days (1) and 75 days (1) interval. Least mean value was calculated in T3 when tomato plants were intercropped with marigold and sprayed with vegetable extract on 75 days interval (0).

Number of insects per plant

Data for number of insects per plant for time intervals showed that all means were insignificantly different from one another (Table 3). As, highest mean value obtained at 75 days' time interval (3.85) with lowest mean value at 15 days' time interval (0). Mean value at 45 days, 60 days and 75 days, time interval did not show significant difference as (2.68), (1.45) and (0.21). As stated in Table 3 the data for number of insects per plant for treatment means showed significant difference from one another. Highest insect population (5.68) was recorded in control T_0 when tomato plants planted without any treatment while least mean value was calculated in T_2 when Tomato plants sprayed with vegetable extract (0.52). Mean values for T_3 when tomato plants were intercropped with marigold and sprayed with vegetable extract (0.10) and T_1 when plants intercropped with marigold (0.40) was not significantly different. So, data showed that in control T_0 when tomato plants planted without any treatment showed extreme number of insects per plant which caused a higher level of destruction in tomato crop while number of insects per plant was reduced because of the effect of marigold and spray of vegetable extract. As stated in Table 3 the data for both time and treatment of number of insect per plant did not showed a significant trend in all mean values as highest mean value was recorded in control To when tomato plants planted without any treatment at 75 days interval (14.68) following by control To when tomato plants planted without any treatment at 60 days interval

(10.18). Least mean value was recorded in T_2 when tomato plants were sprayed with vegetable extract on 75 days, time interval (0.00). Fruit borer larva was found at minimum when tomato was intercropped and maximum in sole crop tomato.

Table 3 Effect of marigold as a companion crop and foliar application of vegetable extract on number of damaged fruits per plant, type of insect per plant, insect population per plant in tomato

Treatments	Days	NDFPP	TIPP	IPPP
T_0	15	0.000^{h}	0.000^{c}	0.000^{d}
	30	0.000^{h}	0.000^{c}	0.000^{d}
	45	1.8125^{cd}	1.000^{a}	3.562^{c}
	60	2.6250^{b}	1.000^{a}	10.188^{b}
	75	4.1875^{a}	1.000^{a}	14.688^{a}
T_1	15	0.000^{h}	0.000^{c}	0.000^{d}
	30	0.000^{h}	0.000^{c}	0.000^{d}
	45	0.687^{fg}	0.500^{b}	2.000^{cd}
	60	1.500^{de}	0.500^{b}	0.000^{d}
	75	2.250^{bc}	0.000^{c}	0.000^{d}
T_2	15	0.000^{h}	0.250^{bc}	0.000^{d}
	30	0.000^{h}	0.250^{bc}	0.875^{d}
	45	0.437^{gh}	0.000^{c}	0.000^{d}
	60	1.250^{e}	0.000^{c}	0.000^{d}
	75	2.125^{c}	0.000^{c}	0.000^{d}
T_3	15	0.000^{h}	0.500^{b}	0.000^{d}
	30	0.000^{h}	0.000^{c}	0.000^{d}
	45	0.000^{h}	0.000^{c}	0.125^{d}
	60	0.437^{gh}	0.500^{b}	0.250^{d}
	75	1.250^{ef}	0.000^{c}	0.125^{d}

NDFPP = Number of damaged fruits per plant; TIPP = Type of insect per plant; IPPP = Insect population per plant; Means followed by a same letter are not significantly different at p = 0.05

Discussion

The current research study demonstrated that *Solanum lycopersicum* plants intercropped with *Tagetes erecta* and treated with vegetable extract (T3) exhibited the greatest plant height, indicating a synergistic effect of both the companion planting and the biostimulant treatment. This is consistent with the results of Natarajan et al. (2006), who reported significantly enhanced plant height in *S. lycopersicum* grown in *T. erecta*-treated soils compared to those in untreated, pathogen-infected soils. They further observed that whole-plant extracts of *T. erecta* were more effective than stem-only extracts, and that extracts from younger plants (40-day-old) had greater efficacy than those from older plants (70-day-old), aligning with our observation that earlier applications and whole-plant influence had more substantial growth-promoting effects. The enhanced growth observed in our T3 and T2 treatments also supports previous findings that plants like *T. erecta* release natural bioactive compounds, such as allelochemicals, which can influence plant–plant interactions and pest dynamics (Tringovska et al., 2015). These compounds may play a role not only in pest repulsion or attraction of beneficial insects but also in promoting plant growth. Our results suggest that the use of *T. erecta* as a companion plant, especially when combined with vegetable extract application, can significantly improve vegetative growth, possibly by creating a more favorable rhizosphere environment or by reducing biotic stress.

Results on stem diameter support previous research highlighting the beneficial effects of companion planting and foliar applications of natural extracts. Tringovska et al. (2015) reported that certain plants produce allelochemicals capable of attracting beneficial insects and repelling pests, thereby reducing plant stress and indirectly promoting vegetative growth. In our study, tomato plants intercropped with marigold (T1) showed the highest overall mean stem diameter (5.72 cm), suggesting that the allelopathic or pest-repelling properties of *Tagetes erecta* likely created a more favorable growing environment, allowing better stem development. Additionally, the effectiveness of foliar applications in enhancing plant growth was supported by Foidl et al. (2001), who reported that moringa extract can increase yield by 20–35 % through improved root density, leaf expansion, and fruit development. This aligns with our results in T2 and T3, where foliar application of vegetable extract contributed to increased stem diameter compared to the untreated control (T0). The stem diameter in T2 reached a maximum of 8.66 cm at 75 days after transplanting, further confirming the stimulatory role of plant-based foliar treatments. Although no significant differences were observed between T1, T2, and T3 overall, all treated groups outperformed the control, indicating that

both companion cropping and foliar application had positive, though sometimes overlapping effects. These results confirm that integrating bio-friendly strategies such as marigold intercropping and vegetable extract sprays can enhance plant vigor, as reflected in stem diameter improvements.

Findings of the study are consistent with those of Soniya et al. (2021), who reported that botanical extracts, particularly those derived from medicinal and aromatic plants, significantly enhanced vegetative growth parameters, including leaf number, in tomato crops. Similarly, Sohrabi et al. (2024) demonstrated that intercropping tomato with marigold not only reduced pest incidence but also promoted healthier vegetative growth, including increased leaf production. The synergistic effect observed in T3 suggests that combining intercropping with foliar application of natural plant extracts enhances plant vigor more effectively than either treatment alone. This supports the growing body of research advocating for integrated botanical approaches in sustainable agriculture (Sharma & Bipana, 2024).

Our findings clearly indicate that untreated tomato plants (T0) experienced substantially higher leaf damage relative to other treatments. While the vegetable extract alone (T2) reduced pest damage, the most pronounced benefit was observed in treatments involving marigold either alone (T1) or combined with vegetable extract (T3). This aligns well with existing literature and supports the integrated effectiveness of botanical and companion cropping strategies. A recent study by Purba and Muliarta (2024) demonstrated that papaya leaf extract, used as a foliar spray on tomato, not only reduced insect-related fruit damage but also improved plant vigor and yield, emphasizing the value of botanical extracts in pest management and crop enhancement. Companion planting with French marigolds reduced greenhouse whitefly infestations through emission of limonene, a volatile organic compound, offering a chemical deterrent mechanism in addition to aromatic masking (Conboy et al., 2019). A previous research study found that African marigolds effectively acted as a trap crop against the destructive tomato fruit borer (*Helicoverpa armigera*), substantially reducing larval and egg presence in tomatoes (damage dropped from over 50 % in control plots to under 6 %) (Hussain & Bilal, 2007). In greenhouse trials, marigold intercropping suppressed root-knot nematodes with effectiveness up to about 46 %, without compromising tomato yields or quality. Marigold's root exudates contain bioactive compounds (like α-terthienyl) that suppress pathogens (e.g., Alternaria solani, the cause of early blight) and create a less conducive microclimate for fungal development (Wang et al., 2007). This leads to reduced disease incidence via allelopathy and canopy humidity modification. Marigolds release allelochemicals through both roots and foliage that repel insects and nematodes, while their strong odor also confuses pests or serves as a physical and olfactory barrier (Hamaguchi et al., 2019).

Intercropping tomato with marigold, particularly between 40–80 days, was associated with a higher number of flower buds, while the period between 50–90 days corresponded with a greater number of flowers. This supports the beneficial role of marigold as a companion plant in enhancing tomato flowering dynamics, even though the differences in days to initial bud emergence were not statistically significant. This study highlights the role of pest pressure in flower damage and suggests that integrating marigold as a companion plant can help reduce pest impact. Previous studies support this by showing that pot marigold attracts natural enemies like parasitoids of *Tuta absoluta*, while companion plants providing pollen and nectar can improve ecological pest control. Remarkably, Harmonia axyridis, a known biological control agent, has been found to prefer yellow flowers, suggesting marigold's additional role in attracting beneficial insects. Our findings suggest that spraying vegetable extract notably increases the number of fruits per plant. Additionally, marigold intercropping has a positive effect by reducing insect pest attacks, thereby creating favorable conditions for higher fruit production. In contrast, the control treatment (T0) resulted in a significantly lower fruit count due to high susceptibility to pests and diseases, as no protective or growth-enhancing measures were applied. Whitefly is responsible for up to 100 % yield damages which makes it most devastating pest of tomato (Mrosso et al., 2023). Fruit borer larva was found minimum when tomato was intercropped and maximum in sole crop tomato. The mechanism responsible for this reduction of Aphids number on pepper intercrop was due to unsuitable hosts acting as trap plants and barrier resulting to their starvation. Similarly reported that adults and nymphs of aphid and whitefly is reduced by application of extracts (Degri & Yoriyo, 2010). Whiteflies possess severe damage to different crops and gained importance as a major pest, also they found all over the world, so they become a persistent threat to certain crops and reason of decline in yield. In tomato they feed on different parts of plant and cause damage by sucking sap (Mutisya et al., 2016).

Conclusion

The present study shows that marigold intercropping, and foliar application of vegetable extract helped to repel pests in tomato. The combination of marigold intercropping and foliar application of vegetable extract also repel mealy bugs and white fly in tomato significantly. The foliar application of vegetable extract supported the plant growth and development, in addition to help in repelling the pests in tomato by the action of intercropping and foliar application of vegetable extract. Conclusively, this combination decreased the use of conventional pesticides to enhance fruit quality and yield.

Declarations

i. Ethics approval and consent to participate

Ethical approval and informed consent were not required for this study as it did not involve human participants, human data, or animals.

ii. Consent for publication

Consent for publication is not applicable.

iii. Data availability

All data generated or analyzed during this study are included in this article.

iv. Competing interests

Authors have declared that no competing interests exist.

v. Authors' contributions

A.A.Q. carried out the laboratory experiments and contributed to data collection. M.F.A. contributed to the experimental design and performed statistical analyses. U.S.Q. assisted with experimental work, data interpretation, and literature review. K.Z. wrote the initial draft of the manuscript. All authors reviewed and approved the final version of the manuscript.

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viii. SDGs addressed

Zero Hunger, Responsible Consumption and Production, Life on Land, Climate Action

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